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STATUS, NESTING DENSITY, AND MACROHABITAT SELECTION OF RED-SHOULDERED HAWKS IN NORTHERN NEW JERSEY

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Abstract.—Response rates of Red-shouldered Hawks (*Buteo lineatus*) and Red-tailed Hawks (*B. jamaicensis*) to broadcast vocalizations in suitable/marginal Red-shouldered Hawk habitat indicated that the species was not completely isolated by habitat. Red-shouldered Hawk responses were not dependent on the time of day, but occurred more frequently near larger wetlands (>10 ha). Sixteen active nests were found in a 7200-ha survey area representing the densest nesting population reported (0.22 nests/100 ha). Macrohabitats of 14 Red-shouldered Hawk nest sites were compared to 64 unused sites. Results revealed preferences for wetlands, stream bottomlands, small forest openings (owing to wetlands), and coniferous and mixed forest habitats but avoidance of suburban, open water, and deciduous forest habitats. *Received 30 July 1991, accepted 12 Jan. 1992.*

Significant declines of Red-shouldered Hawks (*Buteo lineatus*) on Breeding Bird Survey routes have been observed in the Northeast (reviewed by Titus et al. 1989). Hawk migration data also indicate a significant long-term decline in their numbers from 1946 to 1986 (Bednarz et al. 1990). Several northeastern states have responded to regional declines in nesting populations by listing the species as "threatened" (New York, New Jersey), of "special concern" (New Hampshire, Maryland), or as a candidate for listing (Pennsylvania) (Titus et al. 1989). In New Jersey, the species status has recently been upgraded from threatened to endangered. Studies have shown that nesting Red-tailed Hawks (*B. jamaicensis*) will displace Red-shouldered Hawks when thinning reduces canopy closure and crown volumes of mature stands (Bryant 1986). Recent studies of the Craighead's (1956) study area in Michigan have documented a complete displacement of the Red-shouldered Hawk by the larger and more aggressive Red-tailed Hawk during the 1970s and 1980s (S. Postupalsky, pers. comm.).

In northern New Jersey, we have observed that the majority of the Red-shouldered Hawk nesting population occurs in a small region, the Northern Highlands, where forest fragmentation and urbanization are still limited. The purpose of this investigation was to locate existing nesting territories, determine essential habitat requirements, and determine factors that may affect the current distribution of the Red-shouldered Hawk.

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STUDY AREA

We surveyed the Northern Highlands region of northern New Jersey, north of Routes 80 and 15 to the state line. This area includes Morris, western Passaic, eastern Sussex, and western Bergen counties. Speiser and Bosakowski (1987, 1988) provide a complete description of the study area's forest vegetation and physiognomy. Briefly, the Highlands is extensively forested, with sporadic human developments, mostly suburban. Forests are mostly mature second-growth deciduous forest dominated by oaks (*Quercus* spp.); old-growth forest is extremely rare. Pockets of coniferous growth, including eastern hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*), frequently occur along water courses, around wetlands, or in areas with moist, humic soils.

METHODS

Broadcast surveys.—The survey period for the study was from 28 March to 29 June 1990. The intent of the survey was to find as many breeding Red-shouldered Hawks as possible, but no effort was made to cover systematically the entire study area. Therefore, we used wetland-biased survey sites which were limited to suitable breeding habitat: mature forested wetlands, beaver meadows, and mesic lowland forests. We surveyed nearly all suitable wetlands in the study area (>80%) except for a few extremely remote sites or sites where we could not gain permission to enter property.

Tape-recorded vocalizations of Red-shouldered and Red-tailed hawks were broadcast at 151 sites, including 17 sites which were repeated along (<400 m) the same wetland body. Tapes were broadcast from a portable cassette-deck (Contec Model V83, Japan) at nearly full volume (10 watt output) but with minimal distortion. The unit had two detachable speakers which were mounted back-to-back and hung from available tree branches about 1.5 m from the ground. The tape started with a 30-sec silent period to allow the investigators to seek a concealed position about 20–30 m from the speakers. After the initial silent period, Red-shouldered Hawk vocalizations continued for a 3-min period followed by a 3-min period of silence, and then a 3-min period of Red-tailed Hawk vocalizations.

If Red-shouldered Hawks responded to the first portion of the tape, the Red-tailed Hawk segment was not broadcast in order to avoid further alarm to the residents. If Red-shouldered Hawks responded during the Red-tailed Hawk broadcast, the tape was immediately stopped. At each site, we recorded the time of the start of taped vocalizations and the time of first response. We also recorded the number of birds responding, their sex and age if possible, direction and distance of first response, and the type of response (audio, visual, or both).

Nest searches.—After a positive response, nest searches were initiated in most cases except on private property. We also investigated previously used nests (traditional nest sites) for signs of nesting activity (greenery, incubating females, or protesting males). If the old nest did not show signs of recent activity, a thorough foot search of the area was conducted to look for new nests. A special effort was made to find all active nests in an intensive study area (7200 ha). This area included Wawayanda State Park and the northern Pequannock Watershed where previous field studies (Bosakowski 1990, Speiser, unpubl. data) suggested a high density of nests.

Macrohabitat analysis.—A macrohabitat analysis was performed on 14 nests sites and 64 unused sites in the southern end of the intensive study area where aerial photographs were available. The unused sites were defined as broadcast sites where no Red-shouldered Hawk response were obtained during a 1989 broadcast survey of 11 raptor species (Bosakowski 1990) or where no previous sightings or nests were observed during breeding-bird surveys in 1986–1987 (Benzinger et al. 1988).

At each site, habitat was evaluated within a 300 m radius using winter 1982 aerial

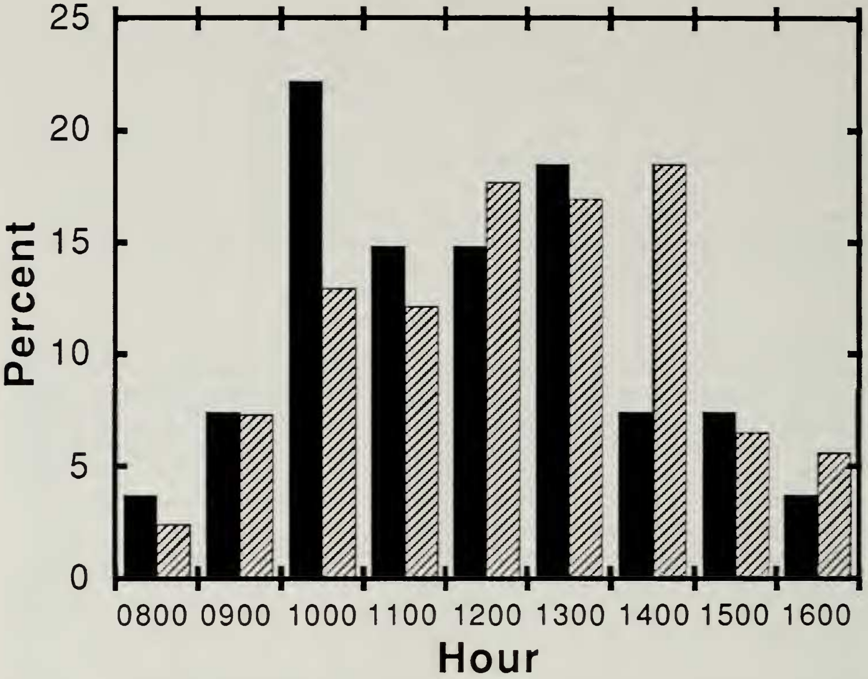

FIG. 1. Hourly response rates of Red-shouldered Hawks to broadcasts of tape-recorded calls during the breeding season. (Black bars = response, N = 27; hatched bars = no response, N = 124.)

photographs (1:8000). Seven macrohabitat types were recognized from aerial photographs, and the areas of each within the habitat circle were measured with a dot grid counter overlay sheet. The length of paved roads and forest edge within the habitat circle were overlayed with a fine thread and measured. Distances to the nearest forest opening larger than 0.5 ha, paved roads, human habitation, streams, lake/ponds (>0.5 ha), and wetlands (>0.5 ha) were measured from aerial photographs. USGS topographic maps were used to determine elevation (±5 m), slope (maximum rise in elevation over a 300 m baseline), and slope location (qualitative ranking: no slope = 0, lower slope = 1, middle slope = 2, and upper slope = 3, after Speiser and Bosakowski 1988). An index of topographic relief was measured as the number of isolines intercepted by 300 m radii in each of the four cardinal directions.

Statistical analysis.—Non-parametric univariate testing was used to compare the 21 macrohabitat variables of nest sites against unused sites. For this purpose, Mann-Whitney *U*-test was applied since non-normal, percentage, and rank data do not require transformations prior to analysis (Zar 1974).

Stepwise discriminant function analysis (DFA) was used to determine how well the variables chosen could discriminate between nest sites versus unused sites. This is determined by a postpriori reclassification procedure (Kachigan 1989) of nest sites and unused sites based on their individual scores from the discriminant function equation. A principal components analysis (PCA) was also run on the data to reveal the most important factors or combination of factors in nest-site selection. This type of analysis reduces a large number

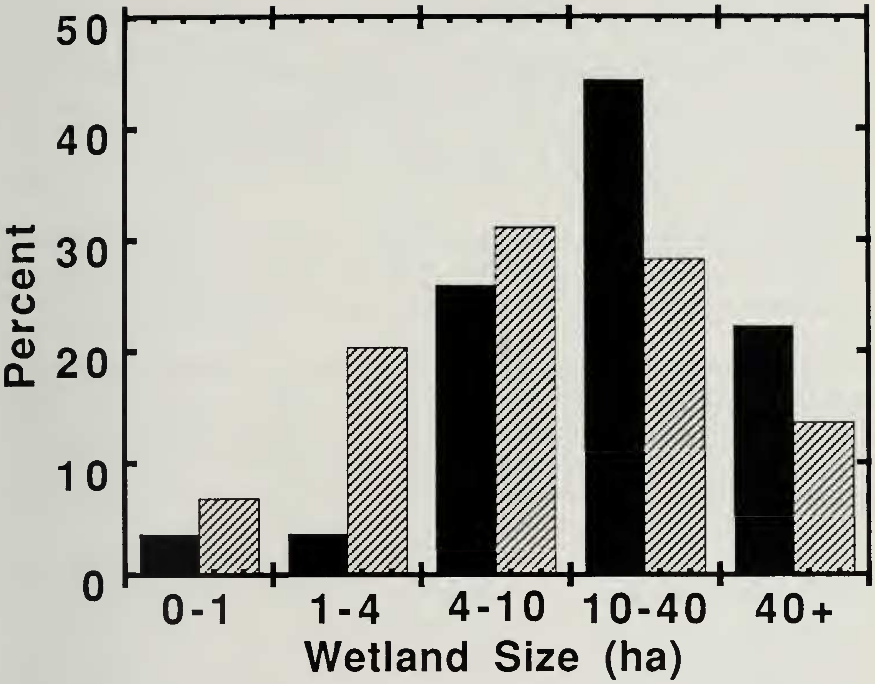

FIG. 2. Response rates of Red-shouldered Hawks to broadcasts relative to wetland size. (Black bars = response, N = 27; hatched bars = no response, N = 103.)

of variables into a smaller number of related factors (Kachigan 1989) which may be useful in identifying significant features of selected habitats.

The multivariate tests were run on a VAX mainframe computer using SPSSx software (SPSS 1988, Norusis 1985), which standardizes all data entries prior to analysis (SPSS 1988). Data reduction procedures were used to remove redundant or highly correlated ($r > 0.7$) variables prior to application of multivariate methods (Green 1979). The variable removed was one of each pair of highly correlated variables that was least interpretable in an ecological sense (Titus and Mosher 1981). Mahalonobis distance was used to standardize data for the discriminant function analysis (SPSS 1988).

RESULTS

Survey response.—Twenty-seven Red-shouldered Hawks responded out of a total of 151 broadcasts. No significant effect of time of day on response rate was found (Fig. 1). Although an overall Chi-square analysis could not be performed because of some low cell frequencies (Zar 1974), the largest differences at 10:00 and 14:00 were not significantly different when tested with Fisher's Exact Test ($P = 0.23$, $P = 0.5$, respectively).

Red-shouldered Hawk responses were classified with regard to the size of the nearest wetland (Fig. 2). Data from additional unused sites along the same wetland body were not included so that the sample size from unused sites is smaller than shown in Fig. 1. A higher ratio of response versus no response by Red-shouldered Hawks occurred in the two largest wetland classes. When the data were pooled into two wetland groups (<10 ha, >10 ha), the percent responses were significantly different (Fisher Exact Test, two-tailed, $P = 0.03$) with a greater response in the larger wetland class.

Red-tailed Hawks responded less frequently (9/112 = 8.0%) compared to Red-shouldered Hawks (27/133 = 20.3%). Spatially, the two species overlapped only at three sites, and heterospecific aggression was observed once.

Including responses made prior to broadcasts and sightings made from extensive foot surveys for nest sites, a total of 61 contacts with Red-shouldered Hawks were made during the study. Eliminating repeat sightings near or on nests, there were 37 different locations which included 17 active nests. Sixteen of the active nests were found in the intensive study area giving a nesting density of 0.22 nests/100 ha.

Macrohabitat selection.—Analysis of 14 Red-shouldered Hawk nest sites revealed that they were located significantly farther from roads and human habitations than unused sites (Table 1). The number of houses within habitat circles around nests tended to be lower than unused sites, but the mean was inflated because one nest had an unusually large number of houses (47). Of the remaining 13 nests, 12 had no houses within the 300-m radius circles. Similarly, nest sites generally had a lower percentage of suburban area than at unused sites, but the mean value was inflated by two outlying nest sites. Road length traversing the habitat circles generally was shorter in Red-shouldered Hawk sites, but the number of roads did not differ significantly from unused sites.

Red-shouldered Hawk nests were significantly closer to wetlands and streams, but not to lakes and forest openings, than were unused sites. Edge length did not differ from that of unused sites. Land cover at Red-shouldered Hawk nests was characterized by significantly greater amounts of wetland, coniferous forest, and mixed forest, and significantly less deciduous forest and less suburban area (lower rank; data not shown in Table 1). Field and open water habitats were not different between groups. Topographically, nests were placed at significantly lower slope locations than unused sites, but overall relief and percent slope did not differ significantly. Nest sites occurred at significantly higher elevations than unused sites.

After data procedures (described in Methods), 16 remaining variables were entered into a stepwise DFA. The analysis reduced the discriminant function into a nine-variable equation (Table 2) which was able to cor-

TABLE 1

MACROHABITAT AT 14 RED-SHOULDERED HAWK NESTS AND 64 UNUSED SITES IN THE INTENSIVE STUDY AREA[a]

Variables	Nest sites (N = 14)	Unused sites (N = 64)	*P* level
Distance to road (m)	812 ± 634	348 ± 304	0.0042*
Distance to human hab. (m)	1013 ± 614	529 ± 468	0.0051*
Distance to stream (m)	64.5 ± 49.9	176 ± 149	0.0021*
Distance to lake (m)	633 ± 308	499 ± 352	0.1798
Distance to wetland (m)	61.3 ± 43.5	436 ± 451	0.0001*
Distance to opening (m)	97.3 ± 61.4	210 ± 200	0.1091
Number of roads	0.57 ± 1.34	0.78 ± 0.97	0.1085
Road length (m)	142 ± 274	320 ± 416	0.0844
Number of houses	3.64 ± 12.5	2.70 ± 5.03	0.0676
Edge length (m)	434 ± 406	538 ± 553	0.7907
Suburban (%)	2.0 ± 6.5	1.9 ± 3.1	0.0595
Field (%)	0.7 ± 1.3	2.7 ± 4.5	0.1584
Wetland (%)	16.0 ± 6.3	5.3± 6.7	0.0001*
Coniferous forest (%)	14.3 ± 19.6	6.3 ± 7.8	0.0488*
Mixed forest (%)	43.3 ± 23.4	9.2 ± 8.7	0.0001*
Deciduous forest (%)	23.6 ± 20.9	69.0 ± 18.6	0.0001*
Open water (%)	0.8 ± 1.3	4.1 ± 8.0	0.5973
Elevation (m)	362.7 ± 128.0	307.1 ± 48.9	0.0001*
Slope (%)	5.3 ± 3.8	6.8 ± 5.2	0.3514
Slope location (0–3)	0.36 ± 0.63	1.25 ± 1.00	0.0017*
Relief (no. of isolines)	11.6 ± 3.0	14.6 ± 6.70	0.1190

[a] Data represent the mean ± SD.

* Difference significant at least at $P < 0.05$ level as determined by two-tailed Mann-Whitney *U*-test.

rectly identify 13 of the 14 nests sites (92.9%) and 100% of the unused sites. The overall correct classification rate was 98.2%, with no unused sites incorrectly classified as nest sites.

A PCA resulted in six factors which explained 70% of the variation in the data set (Table 3). The sixth factor was included since it was only slightly below the normal cut-off eigenvalue of 1.0 (Kachigan 1989) and was explained almost entirely by a single, easily interpreted variable.

The first factor (PC1) had highest correlations with distance to paved roads, distance to human habitation, suburban area, elevation, and mixed forest. PC1 represents a habitat gradient from suburban to wilderness (Fig. 3). The inclusion of mixed forest and elevation is the result of their correlations with remote, undeveloped areas in the study area. This gradient indicates that Red-shouldered Hawks tend to nest in areas with a general absence of human disturbance. The second factor (PC2) had highest correlations with distance to wetlands, wetland area, and slope rep-

TABLE 2

SUMMARY OF A STEPWISE DISCRIMINANT FUNCTION ANALYSIS OF MACROHABITAT AT 14 RED-SHOULDERED HAWK NEST SITES AND 64 UNUSED SITES

Final variables[a]	Standardized canonical coefficient
(a) Dist. human habitation	0.193
(b) Dist. stream	−0.154
(c) Dist. wetland	0.363
(d) Suburban area	0.294
(e) Field area	−0.166
(f) Wetland area	0.756
(g) Coniferous forest area	0.366
(h) Mixed forest area	0.829
(i) Elevation	0.403

Discriminant function equation[a]

$$DF\ I = a(0.000388) + b(-0.00112) + c(0.000883) + d(0.0754) + e(-0.0405) + f(0.114) + g(0.0339) + h(0.0662) + i(0.00274) - 5.390$$

Group centroids:

Nest sites = 3.546

Unused sites = −0.776

Group cut-off score = 2.161

[a] Variables a to i are each weighted by unstandardized canonical coefficients in parentheses.

resenting a habitat gradient from flat wetlands to steep uplands (Fig. 3). Along this axis, Red-shouldered Hawk nest sites were sharply skewed toward the wetland end of the gradient.

The third factor (PC3) had highest correlations with distance to openings, edge length, and field area. Nest sites were centrally located along this gradient compared to unused sites not favoring either extreme of the unused sites. The fourth factor (PC4) had highest correlations with distance to lake/pond and open water area. Nest sites were moderately skewed away from open water environs. The fifth factor (PC5) had highest correlations with distance to stream and slope location with nest sites conspicuously skewed toward bottomland-stream environments. The sixth factor (PC6) had a single very high correlation with coniferous forest area. Along this axis, only some nests sites were sharply skewed towards coniferous areas, but it should be noted that this category was not inclusive of mixed forest.

DISCUSSION

Survey responses.—Red-shouldered Hawks responded to broadcasts at all hours surveyed from 08:00 to 16:00 EST and no significant differences

TABLE 3

SUMMARY STATISTICS OF A PRINCIPAL COMPONENTS ANALYSIS (PCA) OF MACROHABITAT AT 14 RED-SHOULDERED HAWK NESTS AND 64 UNUSED SITES. HIGHEST FACTOR LOADING FOR EACH VARIABLE IS UNDERLINED FOR THAT FACTOR

	Principal component factors					
Statistics[a]	1	2	3	4	5	6
Eigenvalue	3.29	2.68	2.02	1.27	1.01	0.93
Percent of variance	20.6	16.8	12.6	7.9	6.3	5.9
Cumulative percent	20.6	37.4	50.1	58.0	64.3	70.2
Variables	Varimax-rotated factor loadings					
Distance to road	0.788	−0.129	−0.020	0.140	−0.137	−0.270
Distance to human	0.854	−0.027	0.076	−0.146	−0.063	0.102
Distance to stream	−0.028	0.065	−0.845	−0.012	0.873	−0.068
Distance to lake	0.030	−0.043	−0.034	0.822	0.115	0.094
Distance to wetland	−0.162	0.824	0.246	0.114	0.046	−0.145
Distance to opening	−0.001	0.432	−0.693	0.216	0.210	−0.163
Edge length	−0.056	−0.008	0.799	−0.270	−0.108	0.113
Suburban percent	−0.592	−0.195	0.146	0.101	−0.021	−0.068
Field percent	−0.204	0.149	0.799	0.046	0.168	−0.075
Wetland percent	0.162	−0.760	0.078	0.091	−0.286	−0.027
Coniferous percent	0.035	−0.063	0.091	0.126	−0.031	0.949
Mixed percent	0.491	−0.293	−0.003	0.341	−0.205	0.102
Open water percent	0.074	0.025	0.295	−0.820	0.174	−0.016
Elevation	0.685	−0.175	−0.245	0.043	0.125	0.041
Slope %	0.212	0.572	−0.279	−0.232	0.110	0.047
Slope location	−0.051	0.404	0.061	−0.025	0.739	0.057
Group mean factor scores						
Nest sites	0.999	−0.857	0.037	0.533	−0.581	0.394
Unused sites	−0.215	0.185	−0.008	−0.115	0.125	−0.110

[a] Note some variables have been eliminated prior to analysis because of high collinearity (cf Methods).

in time of day were found. However, we purposely avoided broadcasting at earlier or later hours because of diminished levels of thermals at these times.

Response rate increased near larger wetlands, thus suggesting that wetland size appears to be an important component of habitat suitability. Bednarz and Dinsmore (1982) recommended Landsat data to identify potential breeding habitat for Red-shouldered Hawk surveys (0.7% of Iowa), rather than random statewide surveys. The results from this survey show that wetland-biased point samples increased detection rates over random transect counts made in New York, Connecticut, and Wisconsin, but not Maryland (Mosher et al. 1990). Thus, the habitat-biased method may be more desirable for the purpose of a status survey, especially if

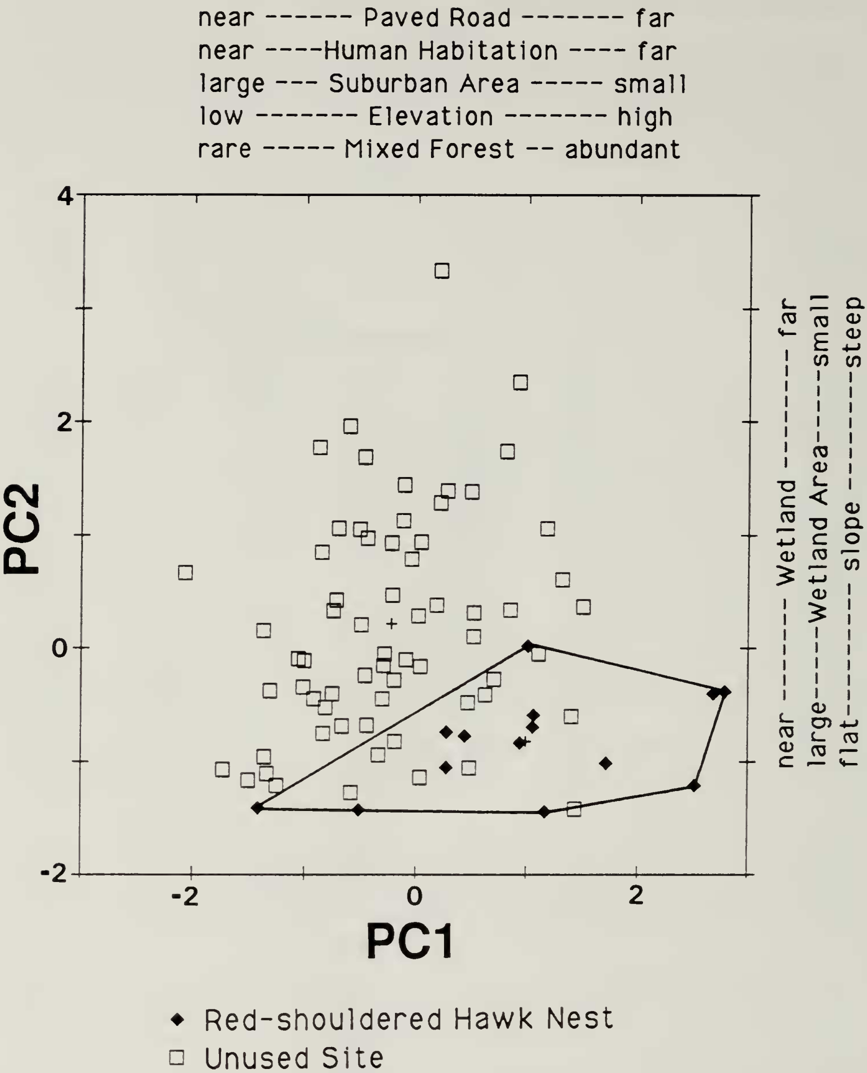

FIG. 3. Two-dimensional plot of principal component scores for macrohabitat of 14 Red-shouldered Hawk nest sites and 64 unused sites along PCA gradients 1 and 2. (+ indicates group centroids.)

field time is limited or the Red-shouldered Hawks are too rare to make random detection efforts worthwhile.

Response rate by Red-shouldered Hawks were greater than Red-tailed Hawks in the wetland-biased survey sites, but the occurrence of both species indicates that they are not completely isolated by habitat partitioning. While spatial overlap of these congeners is generally found to be small (Craighead and Craighead 1956, Sharp and Campbell 1982) or nonexistent (Bosakowski 1990), negative distributions can often represent evidence for competition (Begon et al. 1986). We argue that a small amount of territorial displacement each year could result concomitantly with habitat degradation, thus inducing a chronic, long-term decline of the Red-shouldered Hawk. Moreover, many northeastern states have shown recent increases in breeding Red-tailed Hawk populations (Titus et al. 1989).

Population status.—Nesting density in the intensive study area was 0.22 nests/100 ha, which was substantially higher than the nesting density (0.10 nests/100 ha) reported by the Craighead's (1956) in Michigan farmland (only 11% wooded). Stewart (1949) reported a nesting density of 0.09 nests/100 ha and a territory density of 0.11 pairs/100 ha in Maryland. Henny et al. (1973) studied Stewart's (1949) population but density figures were not comparable since they included only area of river floodplain in their density calculations. To our knowledge, the intensive study area contains the densest population of nesting Red-shouldered Hawks reported to date.

Macrohabitat selection.—Red-shouldered Hawks nested in areas near larger wetlands, closer to streams, and had lower slope locations than unused sites. These preferences confirm wetlands as an important habitat in this region and elsewhere. Bednarz and Dinsmore (1981, 1982, 1985) found nesting Red-shouldered Hawks restricted to river floodplain and bottomland forest in Iowa. Henny et al. (1973) reported on a population nesting along a river floodplain in Maryland, and most Red-shouldered Hawk nests in Arkansas were in floodplain forest or close to water (Preston et al. 1989). In southeastern Missouri, Kimmel and Fredrickson (1981) found 13 of 14 nests in bottomland hardwoods. Portnoy and Dodge (1979) reported on a population occurring in wet deciduous woodland in Massachusetts. Titus and Mosher (1981), Sharp and Campbell (1982), and Morris and Lemon (1983) did not mention positive or negative associations of nest sites and wetlands in Maryland, Ontario, and Quebec, respectively. While the importance of wetlands may vary regionally in response to other variables, the great majority of studies have shown this species to be strongly associated with wetland habitats.

Red-shouldered Hawks in this study also nested in areas having greater proportions of coniferous and mixed forest than expected. A correlation with coniferous growth has been noted previously only by Sharp and Campbell (1982), albeit most studies have been conducted in deciduous forests. We hypothesize that the apparent preference for coniferous forest could be somewhat correlated with the mesic and/or acidic soils of wetlands that are often dominated by eastern hemlock and white pine. Other possible reasons could be that these dense canopied stands may be too thick for nesting by Red-tailed Hawks or may provide concealment from Great Horned Owl (*Bubo virginianus*) predation (Bosakowski et al. 1989).

Few studies have included an analysis of variables which result from encroaching civilization. Bednarz and Dinsmore (1982) found that Red-shouldered Hawks nested significantly farther from buildings than Red-tailed Hawks in Iowa. Interestingly, their mean distance to buildings for Red-shouldered Hawk nests (1001 m) is nearly identical to that of our study region. Armstrong and Euler (1982) observed Red-shouldered Hawks significantly less near lakeshore areas with cottage development, compared to Broad-winged Hawks. Robbins et al. (1989) suggest that the Red-shouldered Hawk is an area-sensitive forest species. Our results show a strong avoidance of development (houses, paved roads) and other factors associated with smaller, fragmented forest tracts (Lovejoy et al. 1986). Bednarz and Dinsmore (1982) and Sharp and Campbell (1982) speculated that development, timber cutting, drainage alteration, and shooting near farms were the most serious threats to Red-shouldered Hawk populations.

Multivariate habitat analysis and management applications.—The DFA results showed that the macrohabitat variables measured in this investigation were extremely accurate in predicting nest sites or unused sites (98.2% classification accuracy). These results demonstrate the importance of macrohabitat for forest-nesting raptors. Bosakowski (1990) has recently reported that forest macrohabitat features can result in equal or even better classification rates than when only forest microhabitat variables (e.g., basal area, stem densities, canopy cover) are used. Furthermore, the latter methods require labor intensive on-site field efforts while macrohabitat can be determined directly from aerial photographs and topographic maps.

The task of measuring maps for future habitat management can be reduced dramatically by applying a stepwise DFA. For example, the 21 original variables measured in our study were reduced to nine variables with a minimal loss of precision for predicting habitat use. Potential habitat could be identified by using site data for the nine variables of the discriminant equation and determining its discriminant score relative to the group cut-off score (Kachigan 1989). Alternately, the PCA results could be used by selecting an important variable from each of the six factors for use in predicting habitat suitability. Either approach may supplement and enhance the effectiveness of field surveys, especially in remote, rugged terrain and might be useful for inclusion into environmental impact surveys in states where the Red-shouldered Hawk is classified as endangered or threatened.

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